

## CHAPTER 1

### INTRODUCTION

#### 1.1 Overview

Robotics research is highly interdisciplinary requiring the integration of control theory with mechanics. The term robot has been applied to a wide variety of mechanical devices. An important class of robots are the manipulator arms, such as the PUMA robot. These manipulators are used primarily in materials handling, welding, assembly, spray painting, grinding, and other manufacturing applications. Robot manipulators are basically multi-degree of freedom positioning devices. The robot, as the plant to be controlled, is a multi-input/multi-output, highly coupled, nonlinear dynamic system.

To achieve higher speed and accuracy for robot manipulator over a wide range of application, the control technique needs to be improved. In general, the dynamic performance of a robot manipulator is directly dependent on the efficiency of the control algorithm and dynamic model of the robot manipulator. Thus the robot manipulator control problem consists of determining the mathematical model of the robot manipulator system and specifying the corresponding control strategies based on these models so that the desired system response and performance is achieved.

The main challenges in the motion control problem are the complexity of the dynamics, and uncertainties, both parametric and dynamic. Parametric uncertainties arise from imprecise knowledge of the dynamics, while dynamic uncertainties arise from joint and link, actuator dynamics, friction, sensor noise, and unknown environment dynamics.

An application of integral sliding mode control (ISMC) based on variable structure system for a three degree of freedom PUMA like robot manipulator is described in this project. This technique suppresses the uncertainties due to parametric variations, and variable payloads.

## **1.2 Objective**

The objectives of this project are as follows:

1. To give a unifying framework for the formulation of the complete mathematical dynamic model of a DC motor actuated revolute robot manipulator in state variable form. The integrated robot manipulator model with joint angle, velocity and acceleration chosen as state variable. The formulations result in nonlinear time varying state equations.
2. To decompose an integrated nonlinear dynamic model of the PUMA like robot manipulator into a system with bounded uncertainties.
3. To control the three DOF PUMA like robot manipulator using Integral Sliding Mode Controller.
4. To compare the performance of Integral Sliding Mode Controller with conventional linear state feedback controller.

### **1.3 Project Scope**

The scopes of this project are:

- Three DOF Permanent Magnet armature controlled DC motor driven PUMA like Robot manipulator as described in [1].
- Simulation work using MATLAB/Simulink as platform.
- Integral Sliding Mode Controller as described in [2].
- Comparison of Integral Sliding Mode Controller with conventional linear state feedback controller

### **1.4 Research Methodology**

The project work consists of three main stages:

- Decomposition of the integrated dynamic model into an uncertain system based on the bounded of the angle, velocity, acceleration, and the payload.
- Two approaches for controlling PUMA Robot
  - First approach utilizing Integral Sliding Mode Controller.
  - Second approach utilizing conventional linear state feedback controller.
- Perform simulation of the two controllers in controlling a three DOF PUMA Robot manipulator using Matlab/Simulink as the platform.

## 1.5 Literature review

Various advanced and sophisticated control strategies have been proposed by numerous researchers for controlling the robot manipulator such that the system is stable as well as the motion of the manipulator arm is maintained along the prescribed path. Some of the control approaches considered in the literature will be presented briefly.

Several control algorithms for robot manipulators based on the variable structure theory have been reported in the literature [3], [4]. Variable structure systems are characterized by a discontinuous feedback control law induces the sliding mode in which the system trajectory lie on the switching surface, which result in insensitivity to parameter variation and disturbances. It is this insensitivity property that enables the elimination of the interactions among the joints of the robot manipulator. The control algorithm does not require an accurate knowledge of the physical parameters of the manipulator, the bounds of the parameters are sufficient to construct the controller Young [3]. However, the discontinuous control law is very difficult for realization in practice and discontinuous controller results in chattering effects of the control signal. To reduce the chattering effects due to the discontinuous control inputs [4] replaced the discontinuous feedback control law with an approximated continuous feedback control law.

Adaptive self-tuning control proposed by [5], used an autogressive model to fit the input-output data from the robot manipulator. The method does not require a detailed mathematical model of the robot manipulator. And the resulting system is insensitive to the changing configurations of the manipulator and variations in the load. However, the dynamic of the manipulator is required to be linearized. Thus, the technique results in a poor system performance over wide range of tasks.

Sliding mode techniques are one approach to solving control problems and are an area of increasing interest. In the formulation of any control problem there will typically be discrepancies between the actual plant and the mathematical model developed for

controller design. This mismatch may be due to any number of factors and it is the engineer's role to ensure the required performance levels exist despite the existence of plant/model mismatches. This has led to the development of so-called robust control methods. However this approach is decreasing the order of the system dynamics, may produce undesirable result in certain application. Other alternative must be introduced to increase the order of the closed-loop dynamics [2].

To overcome the problem of reduced order dynamics, a variety of the sliding mode control known as the Integral Sliding Mode Control has been successfully applied in a variety of control. Different from the conventional SMC design approaches, the order of the motion equation in ISMC is equal to the order of the original system, rather than reduced by the number of dimension of the control input. The method does not require the transformation of the original plant into the canonical form. Moreover, by using this approach, the robustness of the system can be guaranteed throughout the entire response of the system starting from the initial time instance [2].

## 1.6 Layout of Thesis

Chapter 2 deals with the formulation of the integrated dynamic models of revolute robot manipulator. The state space description of the actuator dynamics (DC motor) in form of  $\theta(t)$ ,  $\dot{\theta}(t)$  and  $\ddot{\theta}(t)$ , which are the joint angle, velocity, and acceleration respectively. Derivation of the integrated dynamic model for a three DOF PUMA like Robot manipulator with  $\theta(t)$ ,  $\dot{\theta}(t)$  and  $\ddot{\theta}(t)$  the joint angle, velocity, and acceleration respectively as state variable is developed.

Chapter 3 presents the controller design using integral sliding mode control. A PUMA like robot manipulator is treated as an uncertain system. Based on the allowable range of the position and velocity of the robot arm operation, the model comprising the

nominal and bounded uncertain parts is computed. Then, the centralized control strategy for robot arm based on Integral Sliding Mode Control (ISMC) and also linear state feedback controller are described.

Chapter 4 presents the simulation results of the proposed controllers. The effectiveness of changing the controller parameters as well as the payload on the robot manipulator tracking is presented. Tuning algorithm is presented to assure that the desired tracking response is achieved. The performance of both controllers were evaluated by simulation study using Matlab/Simulink. For the comparison purposes, simulation study on Independent Joint Linear Control is also presented.

Chapter 5 summarizes the results of the research studies. Recommendations and suggestions for future work are also presented.